



Environment
Canada

Environnement
Canada

Conservation
& Protection

Conservation
et Protection

**SPATIAL AND TEMPORAL VARIABILITY
IN SEDIMENT AND WATER CHEMISTRY
IN THE STIKINE RIVER BASIN, B.C.**

**H.P. Schreier , L.M.Churchland
November , 1987**

**Inland Waters and Lands
Pacific and Yukon Region
Vancouver , B.C.**

SPATIAL AND TEMPORAL VARIABILITY IN SEDIMENT AND WATER CHEMISTRY
IN THE STIKINE RIVER BASIN, BRITISH COLUMBIA

H.P. Schreier
Department of Soil Science
Faculty of Agriculture
University of British Columbia
Vancouver, B.C.

L.M. Churchland
Inland Waters and Lands
Environment Canada
Vancouver, B.C.

ABSTRACT

A major power project is being considered for the Stikine River which flows through Northwestern British Columbia and crosses the International border into the Alaskan panhandle. This study is concerned with seasonal and spatial variability in sediment and water chemistry in the Stikine River Basin. Seasonally, the Stikine River exhibits three distinct annual peak flow events caused by snow melt in June, glacial melt in late July, and autumn rain storms in October. Spatially, the geology in the upstream portion of the basin is dominated by volcanic rock while the glaciated downstream portion of the basin is dominated by granodiorite. The study was conducted to determine whether seasonal differences in river discharge and spatial differences in bedrock geology would influence sediment and water chemistry.

A suspended sediment budget was calculated for the 1982 hydrological year and the results showed that the majority of the sediments originated from the Stikine stem of the river above the Iskut River confluence.

Seasonal differences with river flow in the sediment chemistry and clay mineralogy were remarkably small, but the water chemistry data did show the expected decreases in major ion concentrations during the glacial melt period and increases to maximum values during the groundwater dominated winter flow period. Spatial differences in sediment chemistry were observed for Ca, Mg, Si and Fe, giving some support to the hypothesis that sediments originating from the dominantly Mg-Fe-Si rich volcanic rocks in the upper basin are different from those originating from Ca, K, and Na rich granitic and sedimentary rocks which dominate the lower basin.

It was concluded that the regional differences in sediment chemistry throughout the river basin were not sufficiently great to allow predictions on the impact of impoundments on water quality at the International border.

RESUME

Un important projet de développement hydro-électrique est à l'étude pour la rivière Stikine; celle-ci coule à travers le Nord-Ouest de la Colombie-Britannique et franchit la frontière canado-américaine pour déboucher dans la partie sud-est de l'Alaska. Le présent rapport étudie la variabilité spatiale et saisonnière des sédiments et des variables chimiques dans l'eau du bassin de la rivière Stikine. Du point de vue saisonnier, la rivière Stikine montre trois crues distinctes causées par la fonte des neiges en juin, la fonte des glaciers à la fin de juillet, et les orages automnaux en octobre. Du point de vue spatial, la géologie du haut du bassin est dominée par la roche volcanique, tandis que le bas du bassin, sous l'influence des glaciers, est dominé par la granodiorite. Cette étude avait pour but de déterminer si les différences saisonnières dans le flot de la rivière et les différences spatiales de la géologie pouvaient influencer les sédiments et les caractéristiques chimiques de l'eau.

Une étude quantitative des entrées et sorties des sédiments en suspension a été menée pour l'année hydrologique 1982; les résultats montrent que la plus grande partie des sédiments provenait de la portion de la Stikine située en amont de la jonction avec la rivière Iskut.

Les différences saisonnières (reliées au flot) dans la chimie des sédiments et la minéralogie de l'argile étaient remarquablement faibles, mais les variables chimiques de l'eau ont comme prévu montré une diminution des ions majeurs durant la fonte glaciaire et une augmentation maximale durant l'hiver, quand l'influence des eaux souterraines prédomine. Des différences spatiales dans la chimie des sédiments ont été observées pour le calcium, le magnésium, le silicium et le fer, ce qui renforce l'hypothèse selon laquelle les sédiments originaux du haut du bassin, où les roches volcaniques sont riches en magnésium, fer et silicium, sont différents des sédiments originaux du bas du bassin, dont les roches granitiques et sédimentaires sont riches en calcium, potassium et sodium.

La conclusion générale est que les différences régionales dans la chimie de l'eau et des sédiments à travers le bassin de la rivière ne sont pas suffisamment importantes pour prédire l'impact de la retenue des eaux sur leur qualité à la frontière canado-américaine.

ACKNOWLEDGEMENTS

The assistance of J. Taylor, F.T.S. Mah, and W.E. Erlebach, (Water Quality Branch, Vancouver), R. Kwiatkowski (Water Quality Branch, Ottawa), V. Berwick and W. Swanner (USGS Juneau Sub District), Ms. T.D. Nguyen (Soil Science, University of British Columbia, and John and Marilyn Ellis (Wrangell, Alaska) is gratefully acknowledged.

TABLE OF CONTENTS

	<u>PAGE</u>
ABSTRACT	i
RESUME	ii
ACKNOWLEDGEMENTS	iv
TABLE OF CONTENTS	v
LIST OF FIGURES	vi
LIST OF TABLES	vii
1. INTRODUCTION	1
2. DESCRIPTION OF THE STUDY AREA	2
3. METHODS	4
3.1 Sampling Stations	4
3.2 Sampling Frequency	4
3.3 Water Chemistry	5
3.4 Suspended Sediment Chemistry	5
3.5 Suspended Sediment Regime	6
4. RESULTS AND DISCUSSION	6
4.1 Sediment/Discharge Relationships Over Time	6
4.2 Seasonal Differences in Clay Size Mineralogy	8
4.3 Seasonal Differences in Sediment Chemistry	9
4.4 Seasonal Differences in Water Chemistry	9
4.5 Spatial Differences in Discharge/Sediment Relationships	10
4.6 Spatial Differences in Clay Mineralogy	11
4.7 Spatial Differences in Sediment Chemistry	11
4.8 Spatial Differences in Water Chemistry	12
5. CONCLUSIONS	13
5.1 Sediment Distribution	13
5.2 Clay Mineralogy and Sediment Chemistry	13
5.3 Water Chemistry	14
6. LITERATURE CITED	15

LIST OF FIGURES

	<u>PAGE</u>
Figure 1. Map of Stikine River basin showing stations 1 to 7, currently glaciated areas, and areas dominated by volcanic bedrock.	18
Figure 2. River discharge from March, 1981 to March, 1983 at Station 1 in the upper portion of the Stikine River Basin.	19
Figure 3. River discharge from March, 1981 to March, 1983 at Station 7 in the lower portion of the Stikine River basin.	20
Figure 4. Relationship between discharge and suspended sediment concentration at station 7 during the period of daily record from May 28 to October 12, 1982.	21
Figure 5. Differences in suspended sediment loadings transported within the Stikine River basin.	22

LIST OF TABLES

	<u>PAGE</u>
Table 1. Seasonal and spatial differences in particle size.	23
Table 2. Differences in clay mineralogy between stations and sampling time.	24
Table 3. Temporal variability in sediment chemistry.	25
Table 4. Variables which showed significant seasonal differences in sediment chemistry.	26
Table 5. Variables which showed significant seasonal differences in water chemistry.	26
Table 6. Spatial differences in sediment chemistry: upstream vs. downstream differences.	27
Table 7. Spatial differences in water chemistry: upstream vs. downstream differences.	28

1. INTRODUCTION

A major power project is being considered for the Stikine River, which flows through Northwestern British Columbia and crosses the international boundary into the Alaskan panhandle before discharging into the Pacific Ocean. Inland Waters and Lands of the Conservation and Protection Service (Environment Canada), has a mandate to monitor the quality of water crossing the international boundary between Canada and the U.S.

The overall objective of the study was to describe, prior to development, current baseline water quality conditions, emphasizing those variables which would potentially be affected by impoundments. At the inception of this project, water quality data for the Stikine River basin was limited to several samplings a year at the USGS gauging station, near Wrangell, Alaska. Therefore, this represents the first detailed study on the chemistry of suspended sediments and water in the Stikine River basin. An additional objective was to predict, where possible, the potential effects of impoundments on water quality at the Canada/U.S. boundary.

The Stikine River project included studies of lotic biological communities, water and sediment chemistry. This report examines spatial and temporal variability in the chemistry of suspended sediments and water. Other results from the Stikine River study have been published in a data report (Churchland and Schreier, 1984) and an interpretative report (Churchland and Schreier, 1987).

In order to establish a baseline for water quality, it is necessary to understand the relationship between river discharge, suspended sediments, and water chemistry. Concentrations of certain water quality variables including total phosphorus, total metals such as iron, manganese, copper and zinc, and nutrients such as particulate organic carbon are intrinsically tied to the quality and quantity of sediment.

The specific objective of the portion of the study presented in this report was to identify the influence of two major factors on the water and sediment chemistry in the Stikine River basin. We wished to determine whether the three peak flow conditions of snowmelt, glacial melt and Fall floods, and the geographic differences in bedrock geology, produced any systematic differences in water and sediment chemistry. If such systematic differences could be identified the results could be used, with information on the location of dam sites and the expected flow reductions through the year, to predict the potential changes at the international boundary which would result from impoundments.

Water and sediment chemistry in streams affected by glaciers are known to be subject to great temporal and seasonal variation (Slatt 1972, Zeman and Slaymaker 1975, Stednick 1981, Salomons and Forstner 1984). Ongley et al (1981) showed that further work was needed to determine the role of suspended sediments in the transport and accumulation of nutrients in streams. This transport phenomenon may be of particular interest in streams such as the Stikine where turbidity and suspended sediment transport is high throughout the ice-free period.

2. DESCRIPTION OF THE STUDY AREA

The Stikine River originates in the Cordilleran region of north central British Columbia and discharges into the Pacific Ocean near Wrangell, Alaska (Figure 1). The Stikine River has a drainage area of 50,000 km² and includes the Iskut River, a major tributary to the Stikine. Sites in the steep walled canyons of both the Iskut and Stikine Basin are being considered as potential locations for hydroelectric power development. Throughout the middle and lower portions of the basin numerous glaciers occur within a few hundred meters of the main stream channel (Figure 1). The Stikine River is navigable from below the canyon to the mouth but access is difficult and limited to small boats.

The river drains inaccessible and rugged topography and carries a heavy sediment load throughout the period from break-up to freeze-up. The river typically exhibits three annual peak flow periods produced by three distinctly different runoff events which dominate the stream flow throughout the basin. This is most graphically illustrated in the 1982 data of Figure 2 - 3. The first discharge peak occurs during the spring snowmelt period. A slightly less distinct peak flow event occurs in midsummer and can be attributed to the melt of the glacial ice. In late fall (September-October) another peak flow event occurs as a result of extensive Pacific storms which produce heavy orographic rainfall in the coastal region. These fall rainstorms usually create maximum daily mean discharge values for the year in the lower stations of the drainage basin, but this effect diminishes with increasing distance from the coastal zone. At the uppermost station in the basin the fall peak, although often still substantial, is normally exceeded by the spring snowmelt peak and the glacial peak upstream is much less pronounced (Figures 2 - 3).

Since the stream flow regime of the Stikine River is subject to seasonal discharge events it is postulated that these events will influence the amount and type of sediment that is transported. Sediment provenance during snow melt and fall storms is presumed to be a combination of bank and channel sources plus weathering products contributed by interflow and surface runoff. The proportion of bank to overbank sources will be determined by the extent of frozen ground. During glacial melt the sediments should consist mainly of glacial flour rich in primary minerals and 2:1 type clay minerals.

In addition there are major differences in bedrock and surficial geology between the headwaters and the lower portions of the basin. The headwaters portions are dominated by pyroclastic volcanic rocks which cover up to 5000 km² of basaltic intra-canyon spread and

sheet flows (Souther 1972) known as Mt. Edziza, Spectrum Range, Hazelton Mountain, and Stikine River lava flows (Figure 1).

In contrast, the lower portions of the basin are dominated by granodiorite with minor intrusions of sedimentary and metamorphic rocks (Kerr 1948). According to current knowledge of weathering, one would expect a more rapid disintegration and weathering of the dark coloured minerals in the volcanic rock producing a sediment rich in secondary clay minerals, while the sediments from the granodioritic rocks should be dominated by primary minerals (Paton 1978, Birkeland 1983). In addition the sediments produced from the volcanic rocks should be dominated by Mg-Fe silicates, while those from the granodiorite should be higher in Ca, Na and K silicates.

3. METHODS

3.1 Sampling Stations

Seven sampling stations were selected for this project. Sites were chosen to represent conditions in the border reach and near potential dam sites, and were dictated in part by accessibility to this highly remote area. They were three upstream stations (1-3) with road access, one middle stream station (4) accessible only by helicopter, and three downstream (5-7) stations accessible by boat. (Figure 1). Sites were chosen when possible to correspond to water gauging stations operated by the Water Resources Branch, located at stations 1 (08CB001), 4 (08CG004), 5 (08CG001) and 7 (USGS station #15024800).

3.2 Sampling Frequency

The sampling design was such that the temporal variability in sediment and water quality could be examined. Because of the large size and inaccessibility of the basin, the generally poor climatic conditions, and the cost of operating in such a remote area, sampling for water and sediment chemistry was restricted to four trips per hydrological year between June 1981 and February 1983 (Figures 2-3).

Sampling times based on past discharge records were selected to coincide with the three peak flow periods and winter low flow. Each sampling trip was of approximately 6 days duration. Daily discharge and suspended sediment data are available through the publications of the Inland Waters Directorate (1982-84) and the U.S. Geological Survey (1983-84).

3.3 Water Chemistry

At the upstream stations (1-3) and the mid-stream station (4) three samples were collected during each field trip, using a bottle supported by a metal frame. The bottle was submerged and filled as the frame was drawn up through the water column. At the more accessible downstream stations (5-7) three samples were collected with a peristaltic pump from three points across the river. Winter samples were collected from Stations 5, 6 and 7 using a closed sampling bottle within a metal frame which was lowered through three sampling holes cut through the ice. Once the bottle was submerged to between 2-4 meters in depth, the stopper was released and an integrated sample was collected. Water samples were collected in various bottles which had been appropriately treated for subsequent chemical analysis. All water samples were analyzed for nutrients, major ions and total metals using standard methods described by the Inland Waters Directorate (1979).

3.4 Suspended Sediment Chemistry

At each of the 7 sampling sites water from 3 locations was composited. Six to twelve liters were filtered through a 142 mm 0.45 μ filter (S&S) for chemical analysis of suspended sediments. Total elemental analysis was carried out on the < 63 μ sediment size fraction, using an aqua regia (HNO_3 and HCL) and hydrofluoric acid digestion method. (Bennett 1977, Price and Whiteside 1977). The digestion was carried out in a teflon bomb over a 45-minute period at 110°C. Ten ml of 5% boric acid was added to the digest, reheated to 100° for 30 minutes and diluted for analysis with an inductively

coupled plasma spectrophotometer (ICAP). In addition x-ray diffraction analysis was carried out on the clay fraction ($<4\ \mu\text{m}$) using the Mg and K saturation method described by Kittrick and Hope (1963). The samples were then analyzed with a Phillips PW diffractometer.

3.5 Suspended Sediment Regime

Published daily data are available for total suspended sediment concentration and sediment load at stations 1, 4, 5 (Inland Waters Directorate, 1984), and 7 (U.S. Geological Survey, 1983-84). The methods used for sample collections and loading calculations are described in these publications. Daily samples were usually collected with a depth integrated sampler through a single vertical section, with periodic collection of several depth integrated samples across each river section. The daily suspended sediment loads were calculated in these publications by multiplying the daily mean sediment concentration by the daily mean discharge, and applying the appropriate conversion factor. For purposes of direct comparison with Canadian values, U.S.G.S. loading data was converted to metric tonnes.

Analytical methods for total suspended sediment concentration and particle size are as described in Inland Waters Directorate publications (1983-84). Total suspended sediment concentration was determined by either evaporation or filtration, and particle size was determined using the bottom withdrawal technique. Unpublished as well as published data on particle size was used to derive Table 1.

4. RESULTS AND DISCUSSION

4.1 Sediment/Discharge Relationships Over Time

Many studies have shown that there is a relationship between discharge and sediment concentrations. However, as shown by Hem (1970), Glover and Johnson (1974), and Whitfield and Schreier (1981),

all such relationships are time dependent and site specific. A simple discharge/sediment relationship calculated for sampling station #7 nearest the mouth of the river showed a significant overall relationship ($r = +0.56$, $p = <0.05$). However, time related hysteresis is evident (Figure 4). The highest suspended sediment levels precede the snow melt peak. Elevated suspended sediment levels also accompany the snow melt, the fall rainstorms, and the glacial ice melt peak, although the latter is much less pronounced. Figure 4 suggests that the different peak flow periods are of great importance when considering the sediment transport in the Stikine River.

Published data on daily suspended sediment loads for stations 1, 4, 5, and 7 for most of the 1982 ice free flow period (Inland Waters Directorate 1984, U.S. Geological Survey 1983) were used to estimate a total 1982 sediment budget for the three annual peak flow periods. We assumed that little net sediment deposition and resuspension occurs between stations and what is measured at station #7 is the total yearly suspended sediment flux within the basin. This is clearly an oversimplification considering that a large section of the lower Iskut River is extremely braided featuring many depositional land forms.

The relative sediment distribution within the basin can be determined by dividing the sediment data into three general peak flow periods: snow melt (May 28 - June 30), glacial melt (July 1 - August 31), and fall storms (September 1 - October 12, 1982). Overall the snowmelt period produced 45% of the total suspended sediment load while glacial melt amounted to 36% and the fall storms to 19%. The Stikine River Channel produced the largest amount of sediment at all times of the year, but the relative contribution of the Iskut River changed over time (Figure 5). In July and October when the sediment contribution from the Upper Stikine channel is small (4-5%), the Iskut produces 38-40% of the total suspended sediment load at

station 7. In addition, a significant portion of the October sediment contribution (13%) originates between stations 4 and 5. This is a section of the river which is extensively braided and acts as a sediment trap during the June-September period. The coastal storms in October, which have the greatest impact on the lower portion of the river basin, appear to release portions of the deposited sediments during that period. The resuspension of these upstream sediments could mask any geochemical differences between sediments originating in the upper and lower portions of the river.

If we assume that the 1982 discharge record is representative of the average annual flow condition and if we ignore bedload transport, the Stikine Channel supplies the greatest amount of sediment at all times but its relative contribution diminishes between June and October.

Sediment particle size data for stations 5 and 6 (Table 1) show that the clay content in the suspended sediments is greater during the October peak flow than during the June peak flow, with statistically significant differences between June and July at Station 5, June and October at both stations.

4.2 Seasonal Differences in Clay Size Mineralogy

Samples collected during peak flow events between June 1981 and October 1982 were analyzed for clay minerals. Table 2 shows that there is virtually no difference in clay minerals between the different hydrological events in 1981-82. The limited results from two years' field work do not support the hypothesis that the three annual peak flow events, which induce predominantly stream bank erosion during ice break up, rock flour during glacial ice melt, and surface erosion and sediment resuspension during autumn storms, can be separated on the basis of differences in clay mineralogy. The most likely differences were expected for the glacial melt period but it appears that sediments from other sources may confound the picture. Rainfall events in July might be responsible for diluting

the glacial effect. A set of sediment samples obtained during an August 1980 reconnaissance trip did indeed show the expected dominance of primary minerals over secondary minerals in the sediments (Table 2). This suggests that a better mineralogical separation might be possible not at the peak flow in July but at a lower flow in August when the glacial contribution to the sediment flux is proportionally highest.

4.3 Seasonal Differences in Sediment Chemistry

Using the six sets of suspended sediment samples collected through two hydrological cycles, total analysis for 14 elements was performed on the < 63 μ fraction. Differences in chemical composition were again remarkably small (Table 3). A Wilcoxon significance test (Table 4) shows that values for Si and Fe decreased consistently from the June to the July peak flow period. This suggests that the glacial sediments are less rich in these two components. Additional differences were also observed for Mn and P which reached highest annual values and Ti which reached lowest annual values in October. The observations for the latter three parameters are somewhat tentative since data were available for only one complete hydrological cycle. The most important observation is that there are few seasonal trends in the chemical composition of the sediments, for the 14 chemical elements which were tested.

4.4 Seasonal Differences in Water Chemistry

Selected water quality variables were also examined at the peak flow periods and in the winter for two hydrological cycles. For the purpose of this report, fifteen chemical parameters measured in three samples from each station were considered. The complete water quality data set is available in a data report (Churchland and Schreier 1984).

As shown in Table 5, Si, Na, and NO_3 concentrations decreased consistently between June and July, but regained and surpassed June

levels in October and in February. This trend was consistent at all stations and during both 1981 and 1982 hydrological cycles. Chloride and total inorganic carbon (TIC) showed the same pattern and Ca, Mg, Cl and sulfate (SO_4) concentrations were consistently higher at all stations in October and February than in June and July. Iron and to a lesser extent P and Mn values were usually at a maximum during the July peak flow and decreased throughout the rest of the hydrological cycle. These observations suggest that, as shown in other glacial studies (Rainwater and Guy 1961, Zeman and Slaymaker 1975, Collins 1979), the glacial melt period in July exhibits lower solute concentrations than other major discharge periods.

4.5 Spatial Differences in Discharge/Sediment Relationships

Referring to Figure 5, it is evident that in June a significant proportion (50%) of the total suspended sediment load (at Station 7) originates from areas around the headwater stations 1-4. This contribution decreases from 50% to 38% in July and to 31% in October. Furthermore the relative contribution from the upper Stikine diminishes from 27% to 5% in July and 4% in October. Sediment contributions between stations 1 and 6 (50 to 57%) and upstream of station 4 (23 to 33%) are fairly constant for all three flow periods. As previously mentioned, in June and July little additional sediment appears to originate between stations 4 and 5 (1-5%) but in October 13% of the total suspended load originates from the lower Iskut drainage area.

Because of heavy rainfalls in the lower basin particle size data were compared between stations 1, 5, and 6 (Table 1). Percent sand content was higher in the suspended sediments at the upstream than downstream stations for the June freshet period. During the rest of the year suspended sediment concentrations at Station 1 were too low to allow for particle size analysis. Changes in main stream velocity and river morphology, and differences in glacial tributary contribution downstream could account for differences in particle

size. In addition to changes downstream, it was also found that the clay size fraction in the lower Iskut River was higher than in the Stikine during the July peak flow period. This suggests that the influence of volcanic material in producing clay minerals is greater in the Iskut River.

4.6 Spatial Differences in Clay Mineralogy

As can be seen from Table 2, very few spatial differences were observed in the clay mineralogy as the same types of clay minerals in the same relative order of magnitude were found at all stations within the basin.

4.7 Spatial Differences in Sediment Chemistry

Based on total analysis of 14 elements, spatial differences in sediment chemistry were assessed between stations. Only Ca and Mg were found to be good differentiating parameters between locations in the river basin with virtually no differences between the three downstream stations. Ca/Mg can be used to differentiate between the volcanic and granitic bedrocks, the former generally being significantly lower in Ca than the latter. Station 3 has a sediment chemistry which is slightly different from the other upstream stations (1 and 2) suggesting that the sediment chemistry becomes more uniform downstream.

To elaborate on spatial differences the upstream stations 1 and 2 and the downstream stations 5 and 6 were compared in Table 6 and downstream trends were also examined. Small but consistent differences were observed in Fe, Mn, and P values between stations 1 and 2, and in Ca and Mg values between stations 5 and 6. In addition, some consistent trends were also observed in the downstream direction. In both the Stikine and Iskut Channel, Si, Ni and Cr decreased downstream while Ca, Mg, and to a lesser degree, Na, and Ba increased downstream. In addition, both channels showed a significant increase in the Ca/Mg sediment ratio and a decrease in

the Fe/Ca ratio downstream. This confirms that the relative proportion of Mg, Fe, and Si, the dominant components of the volcanic rocks, is higher upstream than downstream. In contrast, Ca, Na, and Ba values more commonly associated with granodiorite and selective sedimentary rocks influence the sediment chemistry downstream.

4.8 Spatial Differences in Water Chemistry

Since three samples were available for all stations and dates, the chemical differences between stations were examined separately for each of the six sampling dates (Table 7). As in the case of the sediments, upstream-downstream differences within each river were greater than upstream-downstream or downstream-downstream differences between rivers. Differences among upstream stations were more pronounced than among downstream stations. The Iskut River in both the upstream and downstream stations were found to have consistently higher Na, Ca, and SO_4 values than the Stikine River. Magnesium showed a similar trend except that the downstream differences were very small. The Si data showed a more complex pattern in that the Stikine headwaters were lower than in the Iskut but downstream the opposite was the case.

Downstream trends showed a consistent increase for Fe, Mn, P, K, and Cl in both channels (Table VII). The downstream decrease in the Mg content was evident in both channels while a similar downstream decrease in Si and SO_4 was only evident in the Iskut Channel. These results suggest that the solute and major ion concentration increases downstream with the exception of Mg and Si which are influenced by volcanic rock conditions in the headwaters.

5. CONCLUSIONS

The Stikine River transports large quantities of sediments throughout the entire ice free period and an understanding of the sediment distribution, sediment quality and water chemistry is essential prior to any hydropower developments. Based on the above findings the following conclusions are made.

5.1 Sediment Distribution

The Stikine River exhibits three distinct annual peak flow conditions: snowmelt in June, glacial ice melt in late July, and late autumn storms in October. The highest total suspended sediment concentrations in 1982 were associated with the pre-snowmelt period. The fall rainstorms produce the second highest suspended sediment values, followed by snowmelt and glacial ice melt. A simple sediment budget for 1982 showed that 45% of the annual suspended load near the mouth occurred during the snowmelt period, 36% during glacial ice melt, and 19% during the autumn storms.

The majority of the sediments originated from the Stikine River channel, but the relative contribution from the Iskut channel increased over the season from a low of 24% of the total suspended sediment load during spring snowmelt to 38% during the glacial melt period, and to 40% during the October storms.

The average clay content in the sediment increased from 21% during the snowmelt to 29% during the October peak flow. During the glacial melt period the clay content in the sediments from the Iskut River was significantly higher than that from the Stikine.

5.2 Clay Mineralogy and Sediment Chemistry

No difference in type and relative dominance of clay minerals was observed in both time and space. In addition the elemental chemistry of the sediments was remarkably uniform at all sampling stations and

at all sampling times. Silica and Fe were the only parameters to show a seasonal effect, decreasing during the glacial melt period. Spatial differences in sediment chemistry were evident for Ca, Mg, and Ba. In addition Si values and Fe/Ca ratios decreased in the downstream direction while Ca, Mg, Na, and Ca/Mg ratios decreased downstream. In most cases these differences were small, but they do reflect the difference in the regional geology. The upstream portion of the basin, which is dominated by Mg-Fe rich volcanic rocks, was consistently lower in Ca and Ca/Mg and consistently higher in Si and Fe/Ca. The importance of Ca, K, and Na is much greater in the dominantly granodiorite and sedimentary rock in the lower basin and this is reflected in these downstream trends. The only notable exception is the increase in Mg and Fe content in the sediments downstream and we suspect that the upstream sampling location in this highly inaccessible area was probably not optimum to elucidate the difference in the geological provenance of the sediments.

5.3 Water Chemistry

Seasonal and spatial effects were more pronounced in the water chemistry. Sodium, Si and nitrate and, to a lesser extent, Ca, Mg, Cl, sulfate and total inorganic carbon reached lowest values during the glacial melt period and highest values in late winter when stream flow is dominated by groundwater.

Spatial differences which reflect the regional bedrock geology were most apparent from Mg and Si. Both showed decreases in the downstream direction and this correlates with decreases in surface exposure of Mg-Fe-silica rich volcanic rock downstream.

It was concluded that regional differences in sediment and water chemistry were not sufficiently great that predictions of the impacts of impoundments on water quality at the international boundary could be made on this basis.

6. LITERATURE CITED

- Bennet, H. (1977). Geochemical analysis of silicates. *The Analyst* 102:153-176.
- Birkeland, P.W. (1983). *Soil and Geomorphology*. Oxford Univ. Press, 372 pp.
- Churchland, L.M. and H. Schreier. (1984). Stikine River Data Report 1981-83. Inland Waters Directorate, Water Quality Branch, Vancouver, B.C., 121 pp.
- Churchland, L.M. and H.P. Schreier. (1987). Water Quality Surveys on the Stikine River. In proceedings of the Technology Workshop Water Quality Monitoring Design. IWD Technical Workshop Series #6, pp. 109-150.
- Collins, D.N. (1979). Hydrochemistry of meltwaters draining from alpine glaciers. *Arctic and Alpine Res.* 11: 307-324.
- Glover, B.J. and P. Johnson (1974). Variations in the natural chemical concentration of river water during flood flow, and the lag effect. *Journ. of Hydr.* 22:303-316.
- Hem, J.D. (1970). Study and interpretations of the chemical characteristics of natural waters. U.S. Geol. Surv. Water Supply Pap. 1475: 271-280.
- Inland Waters Directorate (1979). *Analytical Methods Manual*. IWD, Water Quality Branch, Environment Canada, Ottawa.
- Inland Waters Directorate, Water Resources Branch, Water Survey of Canada. (1982). Surface Water Data, British Columbia. 1981. Ottawa, Canada.

Inland Waters Directorate, Water Resources Branch, Water Survey of Canada. (1983). Surface Water Data, British Columbia, 1982. Ottawa, Canada.

Inland Waters Directorate, Water Resources Branch, Water Survey of Canada. (1984). Surface Water Data, British Columbia, 1983. Ottawa, Canada.

Inland Waters Directorate, Water Resources Branch, Water Survey of Canada. (1984). Sediment Data on Canadian Rivers, 1982. Ottawa, Canada.

Kerr, F.A. (1948). Lower Stikine and Western Iskut River Area, B.C. Geological Survey of Canada. Mem. 246.

Kittrick, J.A. and E.W. Hope (1963). A procedure for particle-size separation of soils for X-ray diffraction analysis. Soil Sci. 96: 319-25.

Ongley, E. M.C. Bynoe and J.B. Percival. (1981). Physical and geochemical characteristics of suspended solids, Wilton Creek, Ontario. Can. Journ. of Earth Sci., 18, 1365-1379.

Paton, T.R. (1978). The formation of soil material. George Allen and Unwin, Ltd., London, pp. 18-44.

Price, W.J. and J.P. Whiteside. (1977). General method of analysis of siliceous materials by atomic absorption spectrophotometry and its application to macro and micro samples. The Analyst 102: 664-671.

Rainwater, F.H. and H.P. Guy. (1961). Some observations on the hydrochemistry and sedimentation of the Chamberlin glacier area, Alaska. US Geol. Surv. Prof. Paper 414C: 1-14.

- Salomons, W. and M. Forstner. (1984). Metals in the Hydrocycle. Springer Verlag Ltd., Berlin, pp. 63-171.
- Slatt, R.M. (1972). Geochemistry of meltwater streams from nine Alaskan glaciers. Geol. Soc. of America Bulletin 83:1125-1132.
- Stednick, J.D. (1981). Hydrochemical balance of an alpine watershed in southeast Alaska. Arctic and Alpine Research 13, 431-438.
- Souther, J.G. (1972). Telegraph Creek map area, B.C. Geological Survey of Canada Paper 71-44, 38p.
- U.S. Geological Survey. 1983. Water Resources Data Alaska, Water Year 1982. USGS Water Data Report AK-81-1 and AK-82-1.
- U.S. Geological Survey. 1984. Water Resources Data Alaska, Water Year 1983. U.S. Geological Survey Water-Data Report AK-83-1.
- Whitfield, P.H. and H. Schreier. (1981). Hysteresis in relationships between discharge and water chemistry in the Fraser River Basin British Columbia. Limnol. and Oceanogr. 26(6): 1179-1182.
- Zeman, L.J. and H.O. Slaymaker. (1975). Hydrochemical Analysis to discriminate variable runoff source areas in an alpine basin. Arctic and Alpine Res. 7:341-351.

FIGURE 1

Map of Stikine River basin showing stations 1 to 7,
currently glaciated areas  , and
areas dominated by volcanic bedrock  .
Arrows indicate locations of proposed dam sites

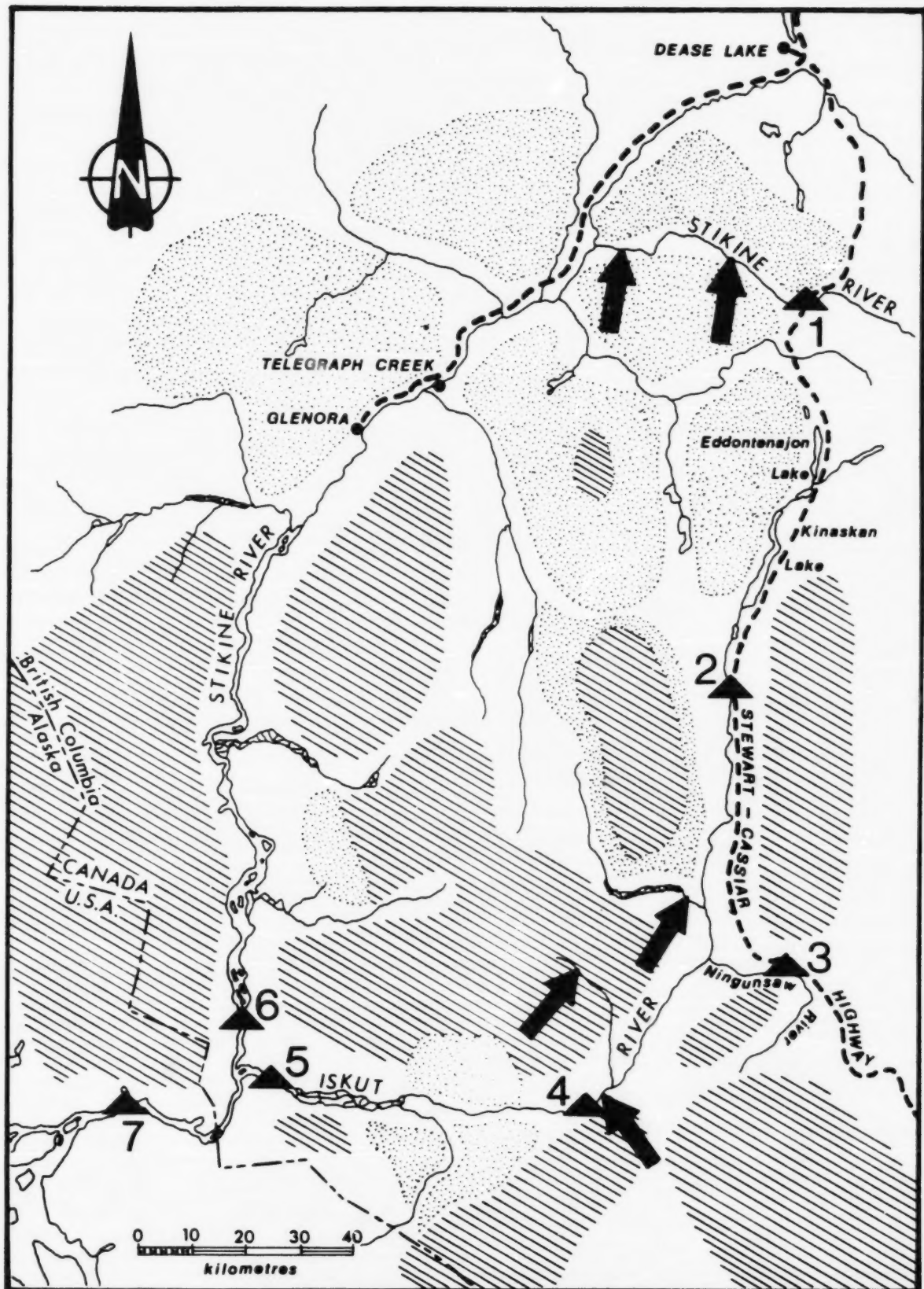


FIGURE 2

River discharge at Station 1 in the upper Stikine River.
(Time, March 1981-March 1983, † indicates sampling dates.)

Station 1

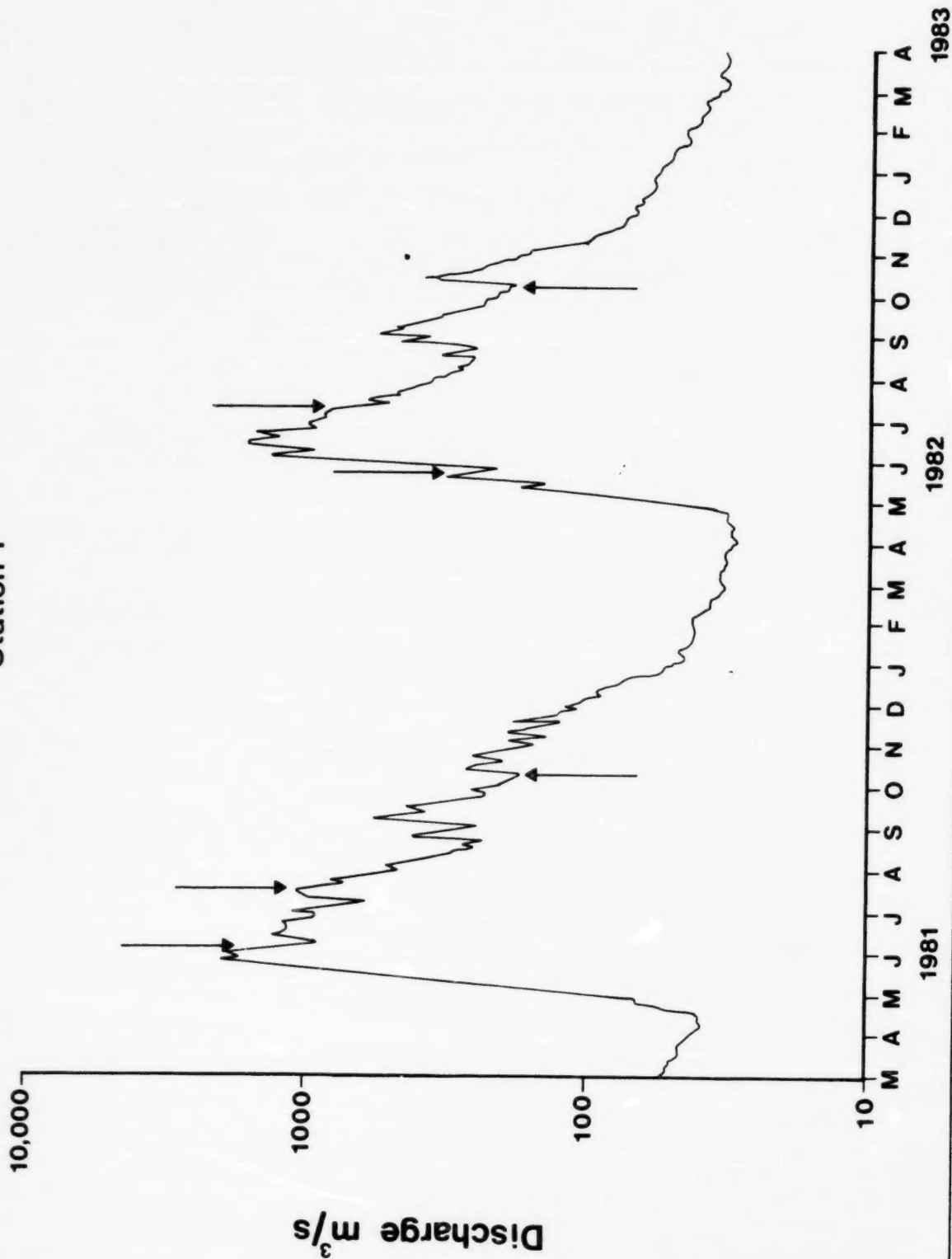


FIGURE 3

River discharge at Station 7 near mouth of Stikine River.
(Time, March 1981-March 1983, ↑ indicates sampling dates.)

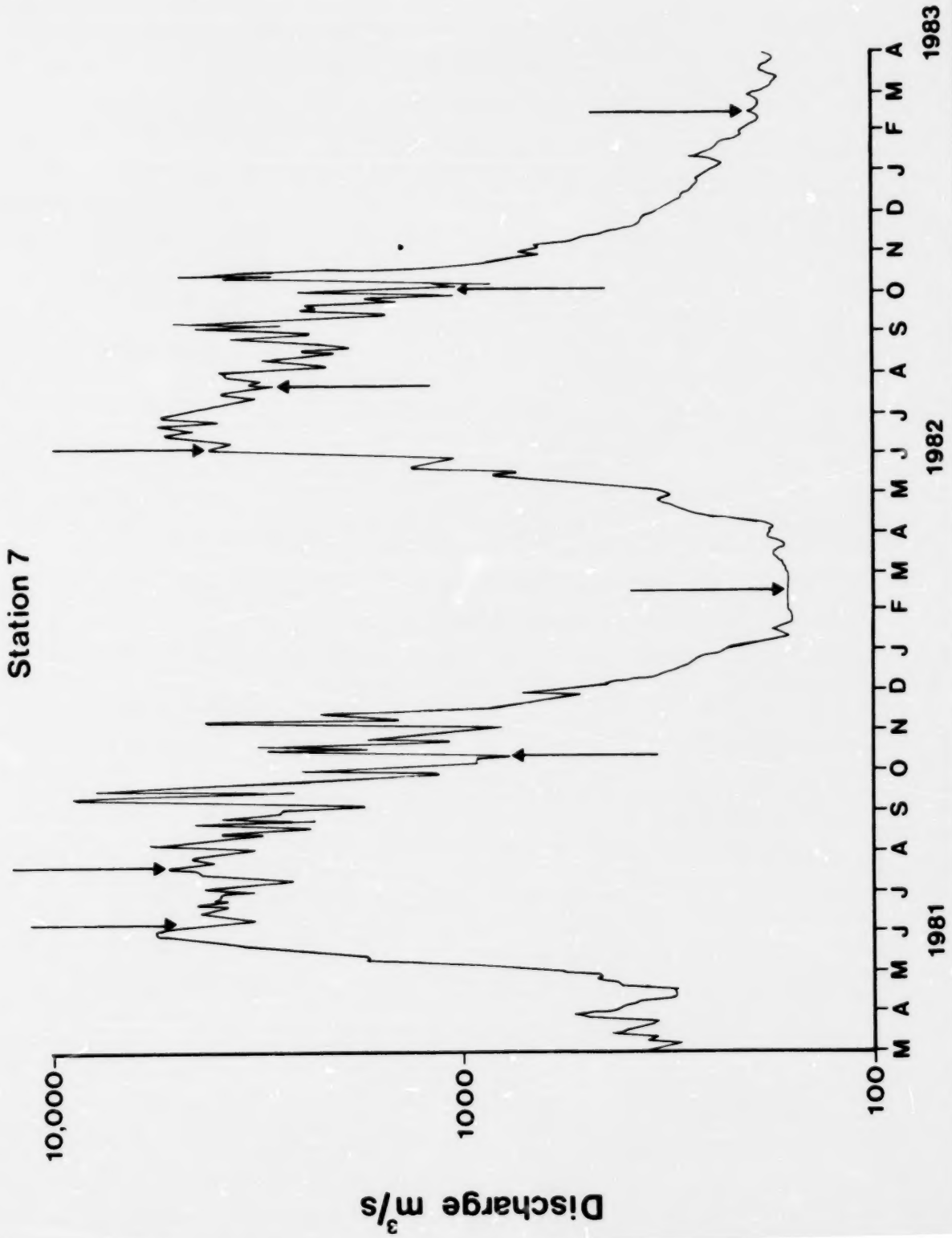


FIGURE 4

Relationship between discharge and suspended sediment concentration
at Station 7 during the period of daily record from
May 28 to October 13, 1982. Numbers indicate
consecutive days of sampling starting from May 28, 1982.
Only the important daily sampling numbers have been included.

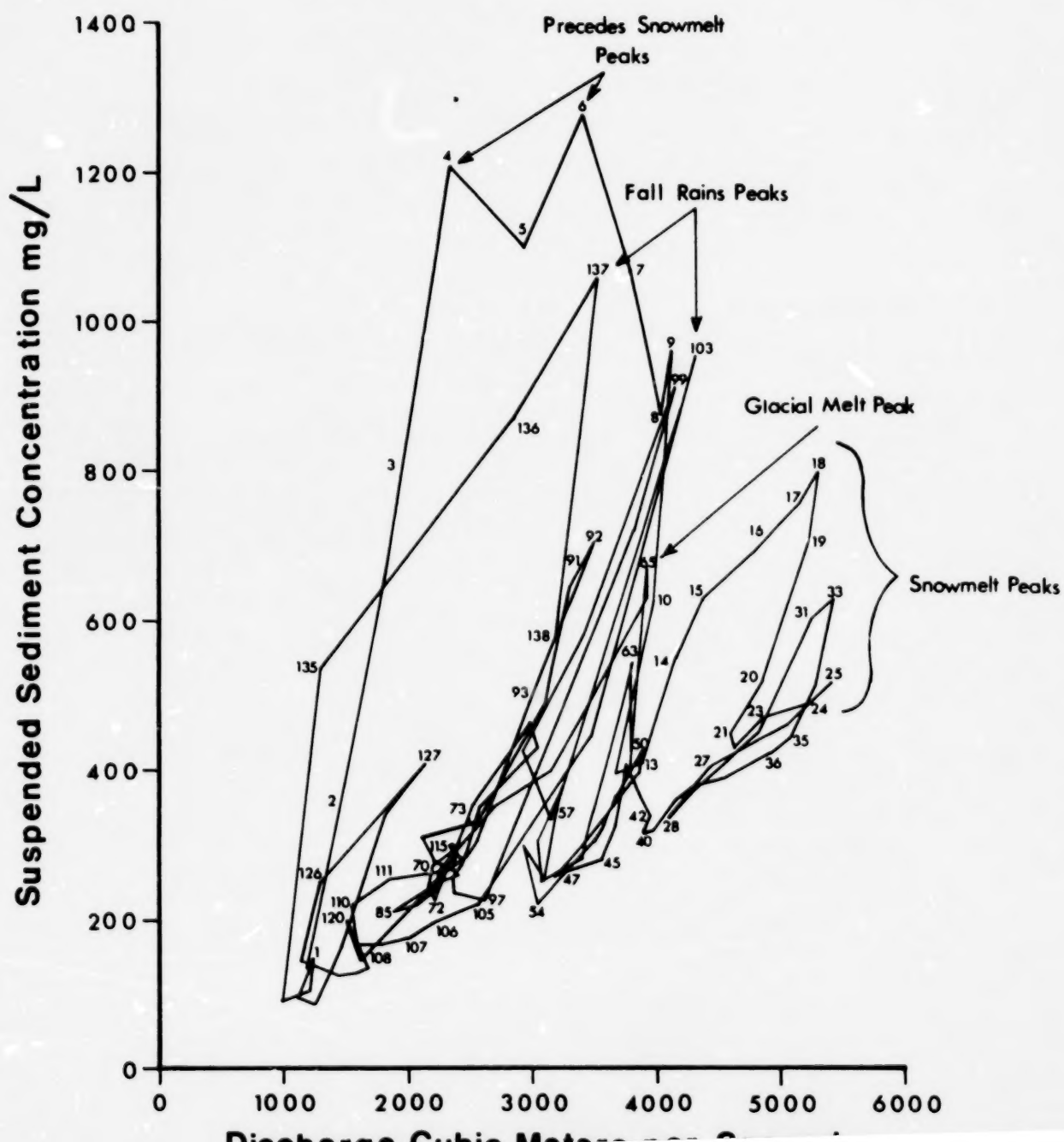


FIGURE 5

Differences in suspended sediment loadings transported within the Stikine river basin (*Estimated from total at Station 7 minus total at Station 5. ND - no data available.)

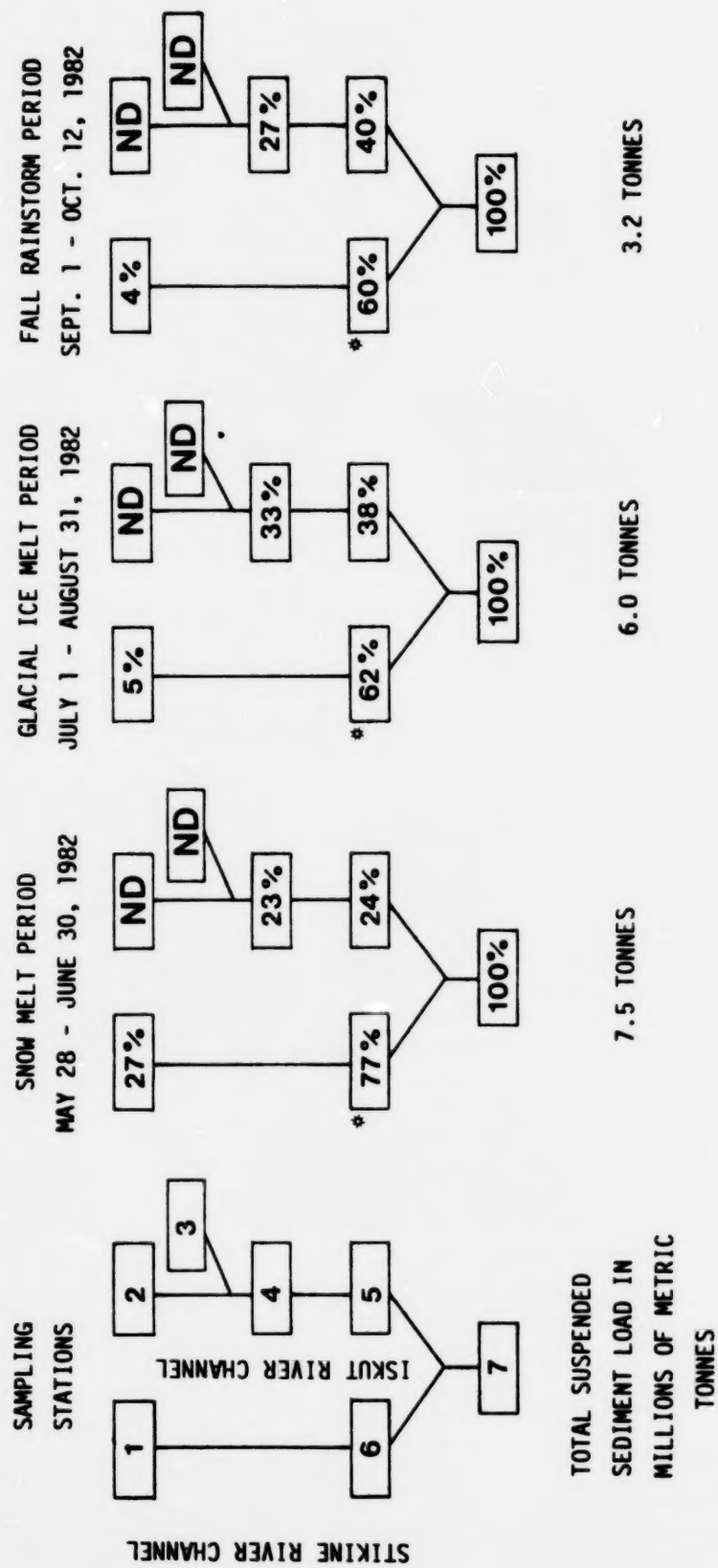


Table 2: Differences in clay mineralogy between stations and sampling times. (1 = Dominant, 2 = Sub-Dominant, T = Trace.)

STIKINE RIVER			ISKUT RIVER		
Sampling Station		Clay Minerals in Sediments	Sampling Station		Clay Minerals in Sediments
		Vermiculite Chlorite Halloysite Kaolinite Mica Feldspar Hornblende Amphibole Quartz Dolomite			Vermiculite Montmorillonite Chlorite Halloysite Kaolinite Mica Feldspar Hornblende Amphibole Quartz Dolomite
USGS (#7) Great Glacier (#6) Hwy. Bridge (#1)		1 1 1 1 2 2 2 2 2 2 1 1 1 1 2 2 2 2 2 2 1 1 1 1 2 2 2 2 2 2	Johnson (#5) Snippaker (#4) Burrage (#2) Ningunsaw (#3)	1 1 1 1 2 2 2 2 2 2 1 1 1 1 2 2 2 2 2 2 T 1 1 1 1 2 2 2 2 2 2	June 2-5, 1981
USGS (#7) Great Glacier (#6) Hwy. Bridge (#1)		1 1 1 1 2 2 2 2 2 2 1 1 1 1 2 2 2 2 2 2 1 1 1 1 2 2 2 2 2 2	Johnson (#5) Snippaker (#4) Burrage (#2) Ningunsaw (#3)	1 1 1 1 2 2 2 2 2 2 1 1 1 1 2 2 2 2 2 2 1 1 1 1 2 2 2 2 2 2	July 19-23, 1981
USGS (#7) Great Glacier (#6) Hwy. Bridge (#1)		1 2 1 1 1 1 2 2 1 1 2 1 1 1 2 2	Johnson (#5) Snippaker (#4) Burrage (#2) Ningunsaw (#3)	T 1 1 1 2 2 2 2 1 1 2 2 2	Oct. 12-15, 1981
USGS (#7) Great Glacier (#6) Hwy. Bridge (#1)		T 1 1 1 1 1 2 2 T 2 1 1 1 1 2 2 2 1 1 2 1 2 2	Johnson (#5) Snippaker (#4) Burrage (#2) Ningunsaw (#3)	2 1 1 2 1 2 2 2 1 1 2 1 2 2 2 1 1 2 1 2 2	May 23 - June 7, 1982
USGS (#7) Great Glacier (#6) Hwy. Bridge (#1)		1 1 1 1 1 2 2 1 1 1 1 1 2 2 2 2 1 1 1 2 2	Johnson (#5) Snippaker (#4) Burrage (#2) Ningunsaw (#3)	2 1 1 1 1 2 2 1 1 1 1 1 2 2 1 1 1 1 1 2 2	July 9-21, 1982
USGS (#7) Great Glacier (#6) Hwy. Bridge (#1)		1 1 1 1 1 2 2 1 1 1 1 1 2 2	Johnson (#5) Snippaker (#4) Burrage (#2) Ningunsaw (#3)	1 1 1 1 2 2 2 1 1 1 1 2 2 2 T 1 1 1 2 2 2	Oct. 2-9, 1982
USGS (#7) Great Glacier (#6)		1 1 1 1 1 2 2 1 1 1 1 1 2 2	Johnson (#5) Snippaker (#4)	1 1 1 1 2 2 2 1 1 1 1 2 2 2	Aug. 13-15, 1980

TABLE 3:

TEMPORAL VARIABILITY IN SEDIMENT CHEMISTRY

Date	Ba μg/g	Cr μg/g	Cu μg/g	Mn μg/g	Ni μg/g	Zn μg/g	Ti μg/g
6/81	990 (760-1210)	243 (137-559)	268 (77-1140)	1123 (1000-1180)	136 (60-368)	309 (112-1220)	4370 (829-5390)
7/81	-	307 (171-600)	-	-	100	340 (152-590)	-
10/81	-	280 (182-476)	232 (209-248)	-	100	235 (216-257)	-
6/82	903 (834-964)	130 (93-200)	94 (67-180)	1029 (887-1170)	96 (50-180)	284 (125-563)	4076 (3360-4610)
7/82	835 (603-978)	125 (89-194)	70 (54-85)	974 (724-1230)	93 (56-160)	330 (92-577)	3709 (3390-4120)
10/82	862 (691-1060)	127 (89-203)	91 (72-113)	1472 (993-1860)	87 (50-170)	267 (227-325)	3115 (2760-3410)

	Si mg/g	Hg mg/g	P μg/g	Ca mg/g	Na mg/g	Al mg/g	Fe mg/g
6/81	270 (197-467)	18.9 (15.2-21.4)	1002 (802-1350)	15.9 (9.2-26.1)	25.3 (19.8-33.3)	88.3 (80.1-94.5)	54.0 (45.7-59.2)
7/81	174 (150-190)	18.1 (10.4-24.3)	-	12.6 (4.0-27.3)	-	67.3 (60.0-77.2)	45.5 (36.1-50.5)
10/81	164 (163-165)	15.8 (12.3-22.5)	-	16.2 (13.3-18.2)	-	63.6 (60.3-67.2)	46.1 (44.4-48.6)
6/82	255 (229-280)	19.1 (17.1-21.3)	953 (790-1300)	18.6 (9.6-30.7)	15.2 (10.6-18.7)	82.5 (77.2-86.9)	52.4 (46.2-59.9)
7/82	127 (116-158)	19.2 (15.2-22.3)	1207 (1000-1340)	21.4 (7.1-40.5)	16.8 (9.8-24.6)	81.1 (76.9-86.9)	44.0 (37.2-49.9)
10/82	197 (89-290)	21.0 (15.5-24.3)	1296 (1110-1430)	17.4 (9.0-29.5)	16.8 (13.0-20.1)	84.8 (76.8-99.7)	46.9 (40.3-56.0)

NOTE: Numbers are means and ranges of values from the 7 sampling stations. - indicates insufficient sediment for chemical analysis.

Table 4: Variables which showed significant seasonal differences in sediment chemistry.

	JULY n=14	OCTOBER n=7	PARAMETERS CONSIDERED
June n=14	Fe ¹ Si ¹	Mn ² P ² Ti ^{3*}	Al Ba Ca Mg Cr Cu Fe Mn Na
July n=14		Mn ² Ti ³ *	Ni P Si Ti Zn
1 = Consistently lower during July at all seven stations 2 = Consistently higher during October at all seven stations 3 = Consistently lower during October at all seven stations * Complete data only for 1982 seasonal comparisons Based on Wilcoxon's matched pairs test ($\alpha = 0.05$)			

Table 5: Variables which showed significant seasonal differences in water chemistry.

	JULY n=42	OCTOBER n=42	FEBRUARY n=18	PARAMETERS CONSIDERED
June n=42	Na ¹ Si ¹ NO ₃ ¹	Na ² Si ² NO ₃ ² Ca ² Mg ² SO ₄ ² Cl ² TIC ² Mn ⁴ Fe ⁴	Na ³ Si ³ NO ₃ ³ Ca ³ Mg ³ SO ₄ ³ Cl ³ TIC ³ Fe ⁵ Mn ⁵	Ca Fe Mg Mn Cu Zn Na P Si K Cl SO ₄ NO ₃ TIC TOC
July n=42		Na ² Si ² NO ₃ ² Ca ² Mg ² SO ₄ ² Cl ² TIC ² Fe ⁴ P ⁴ Mn ⁴	Na ³ Si ³ NO ₃ ³ Ca ³ Mg ³ SO ₄ ³ Cl ³ TIC ³ Fe ⁵ P ⁵ Mn ⁵	
October n=42			Na ³ Si ³ NO ₃ ³ Ca ³ Mg ³ SO ₄ ³ Cl ³ TIC ³ Fe ⁵ P ⁵ Mn ⁵	
1 = Consistently lower during July at all seven stations 2 = Consistently higher during October at all seven stations 3 = Consistently higher during February at all seven stations 4 = Consistently lower during October at all seven stations 5 = Consistently lower during February at three stations in the lower river Based on Wilcoxons Matched Pairs Test (α = 0.05)				

Table 6: Spatial differences in sediment chemistry: upstream vs. downstream differences.

	STIKINE UPSTREAM STATION 1 n=6	ISKUT UPSTREAM STATION 2 n=6	ISKUT DOWNSTREAM STATION 5 n=6
STIKINE UPSTREAM STATION 1 n=6		Differences between Upstream Stations Fe ¹ Mn ¹ P ¹	
ISKUT DOWNSTREAM STATION 5 n=6		Differences Downstream Iskut Ni ³ Cr ³ Fe/Ca ³ Ca/Mg ² Ca ² Mg ² Ba ²	
STIKINE DOWNSTREAM STATION 6 n=6	Differences Downstream Stikine Si ³ Ni ³ Cr ³ Fe/Ca ³ Na ² Ca ² Mg ² Ca/Mg ²		Differences between Downstream Stations Mg ⁴ Ca ⁴
1 = values at station 1 < 2 at all six sampling times 2 = values increase downstream at all six sampling times 3 = values decrease downstream at all six sampling times 4 = values at station 5 < 6 at all six sampling times 5 = values at station 5 > 6 at all six sampling times Based on Wilcoxon's Matched Pairs Test ($\alpha = 0.05$)			

Table 7: Spatial differences in water chemistry: upstream vs. downstream differences.

	STIKINE UPSTREAM STATION 1 n=18	ISKUT UPSTREAM STATION 2 n=18	ISKUT DOWNSTREAM STATION 5 n=18
STIKINE UPSTREAM STATION 1 n=18		Difference between Upstream Stations Mg ¹ Na ¹ Si ¹ SO ₄ ¹ Ca ¹	
ISKUT DOWNSTREAM STATION 5 n=18		Differences Downstream Iskut Fe ² Mn ² P ² K ² Cl ² SO ₄ ³ Mg ³ Si ³	
STIKINE DOWNSTREAM STATION 6 n=18	Differences Downstream Stikine Ca ² Fe ² Mn ² P ² K ² Cl ² NO ₃ ² TIC ² Mg ³		Differences between Downstream Stations Na ⁴ Ca ⁴ SO ₄ ⁴ Si ⁵
1 = values at station 1 < 2 at all six sampling times 2 = values increase downstream at all six sampling times 3 = values decrease downstream at all six sampling times 4 = values at station 5 > 6 at all six sampling times 5 = values at station 5 < 6 at all six sampling times Based on Wilcoxon's Matched Pairs Test ($\alpha = 0.05$) Parameters considered: Ca Cl Cu Fe K Mg Mn Na NO₃ P SO₄ Si TIC TOC Zn			